Space Communications Technology Link

A publication which reports upon the news and events of the Space Communications Program
NASA Lewis Research Center • Volume 1, No. 2 • December 1998

Changing the way NASA and the Nation Communicate through Space

Evolving Enterprise Relevance

James M. Budinger and Charles A. Raquet
Space Communications Program

A Cleveland area high school science class conducts an experiment to observe up close the flames of a fuel burning in a combustion chamber. Not too unusual, unless you consider that the laboratory is onboard the International Space Station orbiting the Earth. Changes to the experiment configuration and its test parameters are made from a personal computer via the internet. The class observes the results in high definition video displayed on HDTV monitors in the room. A flat panel antenna for the commercial satellite transceiver blends invisibly into the glass of the classroom window.

The first decade of the new millennium will bring about significant changes in the way NASA conducts its space missions. Lewis Research Center's Space Communications Program (SCP) will be heavily involved in enabling at least two new ways for NASA to conduct its business in space – commercial asset utilization and space-based internet.

Recognizing the exploding growth of both the internet and the commercial satcom industry sector, one of our three major program sponsors has made a strategic decision to leverage commercial communications services and technologies to the greatest extent possible. Within the Human Exploration and Development of Space Enterprise, the Space Operations Management Office (SOMO) sponsors Lewis to help close the tech-nology gaps, therefore, allowing the Agency to use emerging commercial assets for all of its space communications needs.

Two "***Project Updates***" articles in this issue address some of the efforts we have undertaken to enable this vision. Our commercial partners as well as SOMO sponsors agree that the recently completed "118x" ACTS experiments described in this article have gone a long way toward opening up the possibility of NASA spacecraft being served as nodes on the internet. Demonstrating benefits to both the Agency and our commercial partners, the article on Direct Data Distribution (D^3), such as the flat panel antenna visualized in the first paragraph

(continued on page 2)

In this Issue . . .

(continued from page 1)

of this article, illustrates how NASA missions in near-Earth orbit can leverage commercially provided telecommunications services and equipment.

Under the Space Science Enterprise, we are sponsored to conduct applied research and proof-of-concept technology that pertains to multiple Enterprises and their missions. Breakthroughs leading to significant improvement in the size, mass and efficiency of critical communications components and techniques are featured in several articles in this issue's "***In the News***" section.

Our third major sponsor adopted a new name this past October, to better describe its purpose in the next millennium. The Office of Aero-Space Technology funds some of our work at both ends of the technology development spectrum. This issue contains articles featuring success stories from the Directors Discretionary Research Fund and Small Disadvantaged Business partnership. Another "***Project Updates***" article describes how Lewis technology is working with other NASA centers, the Federal Aviation Administration, and commercial service and technology providers to help make the air travel in the future safer, less expensive, and easier on the environment. Finally, look for selected Lewis Space Communications Program accomplishments and recent activities featured in a collection of articles in the section "***We're Out There***".

This publication of the Space Communications Technology Link newsletter addresses the achievements by NASA's Space Communications Program this past fall quarter of 1998.

If you have ideas or suggestions for topics that you'd like to see presented in future issues of the ***"Space Communications Program Technology Link"***, please let us know. We're here to serve you, our customers, and to change the way NASA and the Nation communicate through space.

For more information about the Space Communications Program at NASA Lewis Research center, please e-mail:

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and refer to Article 1298–1

NASA Lewis Research Center Develops Silicon and Silicon/ Germanium Monolithic Integrated Circuits for RF Systems

George E. Ponchak, Ph.D.
Electron Device Technology Branch
Communication Technology Division

Silicon (Si) integrated circuits are responsible for all of the advances made by mankind over the past forty years. While some may argue the truth of that statement, consider designing a bridge, building, or other construction project without a computer. Imagine communications without email, faxes, and wireless telephones. Everything in our lives including automobiles, toys, household appliances, and machine tools rely on Si integrated circuits.

For twenty years though, microwave engineers could not use Si because its material properties limit transistors to operation below a few gigahertz (GHz), or the frequency of your wireless telephone. Therefore, for the new Ka-band satellite systems, ACTS, local multipoint distribution systems, secure communications, radar, and many other applications, microwave engineers developed Gallium Arsenide (GaAs) and Indium Phosphide (InP) integrated circuits. However, these materials cannot be monolithically integrated with all of the other electronics

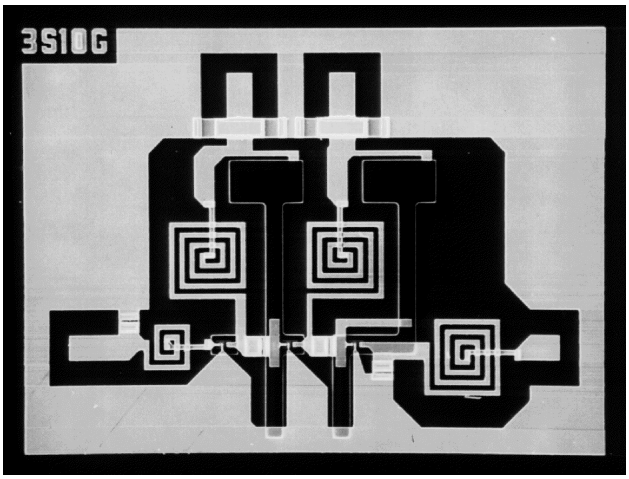

Figure 1.—X band three-stage amplifier fabricated by the University of Michigan.

fabricated on Si, and they cannot be fabricated with the same processes. Thus, cost and system size is higher than desired.

Realizing this, the Electron Device Technology Branch started a research effort to develop Si and a related material, Silicon Germanium (SiGe), microwave integrated circuits in 1991. Since obtaining good materials is critical to developing microwave transistors, Dr. Samuel Alterovitz led an effort at NASA Lewis Research Center to develop a non-destructive method of characterizing the new material structures that were going to be required. This was the first time this characterization method called ellipsometry was used to measure SiGe structures. Success with this led to collaborations with Dr. Edward Croke III of HRL Laboratories LLC to grow SiGe layers with high Ge content by Molecular Beam Epitaxy (MBE). In parallel, an effort to fabricate Heterojunction Bipolar Transistors (HBTs) with this new material was started with Prof. Pallab Bhattacharya of the University of Michigan.

Simultaneously, Prof. Linda P. B. Katehi of the University of Michigan and Lewis' Dr. George E. Ponchak were solving the other half of the Si problem. CMOS grade silicon wafers have a resistivity of 1-20 Ohm-cm. Thus, circuit elements and transmission lines placed directly on the substrate have high losses. Through a series of experiments, several alternative transmission line technologies were developed including using high resistivity silicon substrates, thin film transmission lines on polyimide substrates, and micromachined transmission lines.

In 1996, all of these projects were brought together and a collaboration between NASA Lewis Research Center, the University of Michigan, and HRL Laboratories was started to design and fabricate microwave integrated circuits using high Ge content SiGe HBTs. Over the next two years, several excellent papers were presented including the reporting of X and Ku-Band amplifiers such as the one shown in Figure 1. Based on the progress of this collaboration, the Jet Propulsion Laboratory's Center for Integrated Space Microsystems chose the University of Michigan's SiGe technology for the RF communications portion of the system on a chip project. Drs. Alterovitz and Ponchak continue to collaborate with the University of Michigan on this project as scientific advisors and members of the CISM project team. In addition, the Electron Device Technology Branch is developing better transistor contacts, and it is investigating the reliability of SiGe HBTs to assure our NASA partners that this new technology is ready for space missions.

For more information about this topic, visit

http://ctd.lerc.nasa.gov/5620/SiGe.html

or if you are interested in collaborating with us, please e-mail us at:

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and refer to Article 1298-2

SATCOM '98 Proceedings

- Satellite Networks: Architectures, Applications, and Technologies Workshop Conference Publication, NASA/CP-1998-208524 entitled "Satellite Networks: Architectures, Applications, and Technologies", is published.

To inquire about this publication, e-mail us at:

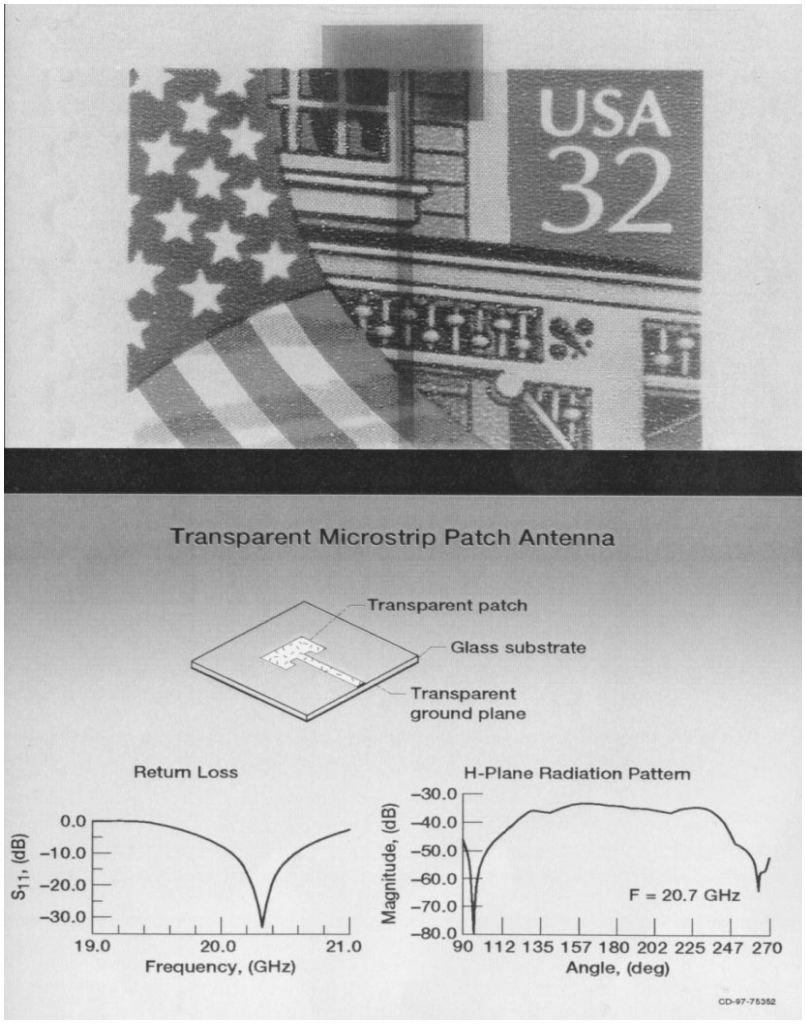
Spacecom@lerc.nasa.gov

Transparent Antenna

Richard R. Kunath
Applied RF Technology Branch
Communication Technology Division

An antenna which uniquely combines the attributes of effectively radiating RF energy while also being optically transparent has been developed and has been patented. The antenna was fabricated using Indium Tin Oxide (ITO) on a glass substrate. The antenna was fabricated in both a microstrip patch and a linear taper slot configuration at radiation frequencies of 20 GHz. The measured performance of both configurations was comparable to the same antenna configurations on conventional dielectric substrates. Additional testing in the 0.3 to 0.8 micrometer wavelengths, revealed a high level of optical transmissibility.

Optically transparent antennas enable “space reuse”, that is, the multiplexing of physical space for both optical imaging and RF transmission. This combination is particularly attractive as a potential solution for applications in which space is limited, such as when an antenna and an optical imaging instrument need to “look” in the same direction. This frequently occurs in earth-observing spacecraft in which nadir-facing space is at a premium. By mounting the data transmission antenna on top of the imaging instrument, special antenna deployment mechanisms can be avoided. The optically transparent antenna also has potential for reusing the space already being used by solar panels. By mounting the antenna over the solar panel, large arrays of antennas, hence



Transparent Microstrip Patch Antenna

high gain antennas, can be established without requiring additional space. An additional potential application is the use of optically transparent antennas on the visors of astronauts that would enable an astronaut to communicate in the same direction as she is looking. An earthbound benefit of this technology is its potential use on computer monitor screens to enable wireless communications links between PCs and wireless terrestrial networks.

This technology development originally began as a Director's Discretionary Fund proposal jointly submitted by both Dr. Richard Lee (a NASA researcher) and Dr. Rainee Simons (at the time a NYMA support service contractor). At the conclusion of this development, NYMA requested to have patent rights transferred to themselves in an effort to directly commercialize the technology for the exploding wireless communications market. Lewis agreed to the technology transfer and NYMA applied for the patent, which has just recently been awarded. In the interim, NYMA was purchased by Federal Data Corporation (Fed Data), and Fed Data, has begun to market this technology to both the commercial wireless communications industry as well as the automotive industry. The transparent antenna is yet another technology transfer success story from the Space Communications technology development program.

For more information please e-mail us at:

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and refer to Article 1298-3

Ferroelectric Technology

Robert Romanofsky and Richard R. Kunath
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Communication Technology Division

Felix Miranda
Electron Device Technology Branch

An exciting and very promising technology currently being developed at LeRC is ferroelectric materials and the frequency and phase agile microwave devices being fabricated with them. It is well known that ferroelectics exhibit strong dielectric nonlinearities. An electric field can be used to tune the dielectric constant thereby affecting the propagation velocity of a wave traveling through the material. Development of ferroelectric materials for microwave applications dates back to the early 1960s when researchers at Raytheon experimented with strontium titanate and barium titanate. Their purpose was to assess the potential of these materials for tunable microwave components, and possibly phased arrays. But waveguide phase shifters based on bulk material suffered from unacceptably high insertion loss, because of the high loss tangent of the material (~0.3 at 3 GHz) and the unreasonably high bias voltage required for tuning (~2 kV). Consequently, most devices in the field today are based on ferromagnetic materials even though they are unwieldy, expensive, and require large drive current.

However, Lewis engineers have devised a phase shifter based on metallic or superconducting coupled microstrip electrodes patterned upon a thin ferroelectric film that was grown by pulsed laser ablation on a $LaAlO_3$ substrate. The Lewis device was the first to demonstrate low loss performance while providing over 360 degrees of continuous phase shift at frequencies approaching 20 GHz. A widespread misconception held that practical thin film phase shifters at higher microwave frequencies were not achievable. Lewis' landmark results published in Applied Physics Letters, are the best reported so far where miniaturization, insertion loss, and total phase delay are of paramount importance, and distinguishing Lewis as the world leaders in this technology.

These Lewis ferroelectric technology developments have been applied to two specific demonstrations. The first was the fabrication and demonstration of a Ku-band, cryogenic, GaAs PHEMT, ferroelectric tunable oscillator. This first-of-a-kind circuit has a center frequency of 160GHz and a tuning range of 3% of the center frequency achieved by applying a 0 to 38 volt bias. Extending the bias voltage to 250 volts resulted in a tuning range of 300 MHz. Spectrum analyzer measurements indicated that this oscillator was very spectrally pure, indicating no measurable spurs or sub-harmonics. This type of oscillator enables the fabrication of low phase noise, small size, and simply implemented local oscillators necessary for the establishment of low bit-error-rates when used to support advanced modulation schemes.

The second demonstration of the Lewis-developed ferroelectric technology has been the continued development of an entirely new class of microwave time delay circuits, commonly referred to as phase shifters. These new

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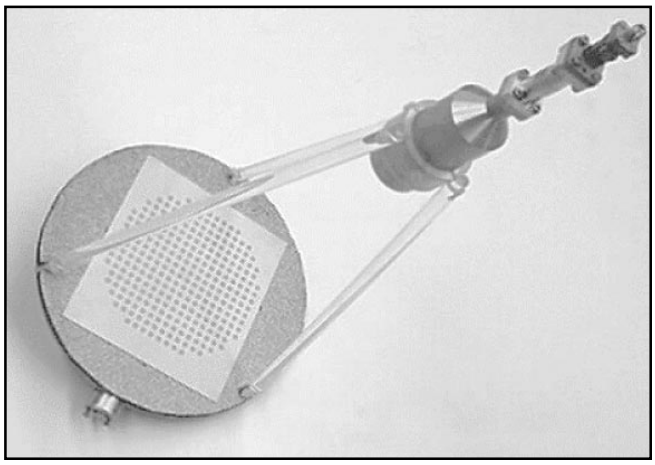
Ferroelectric Technology continued.



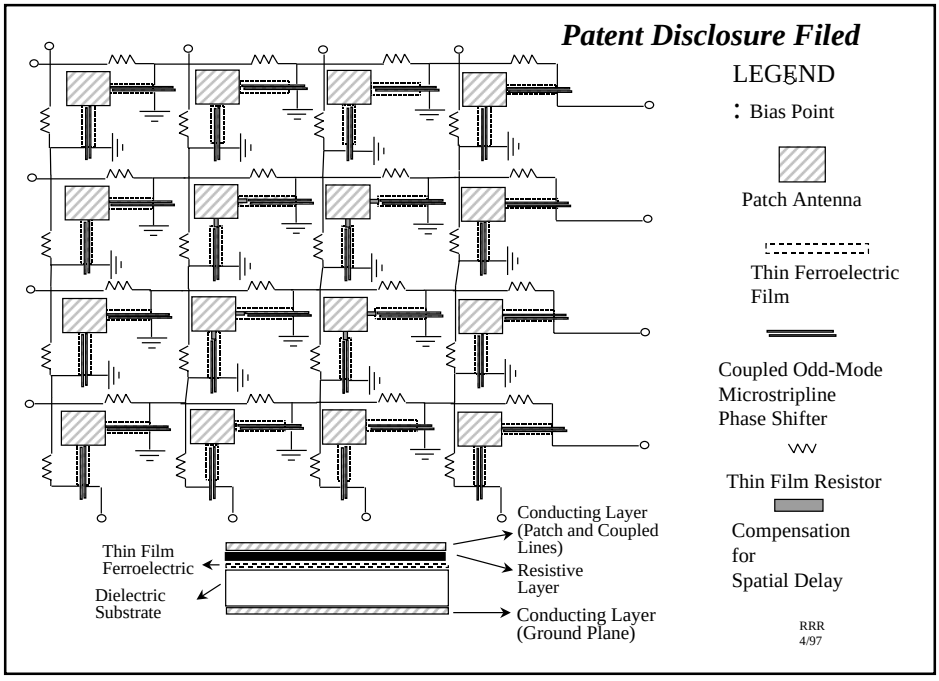
K-band Reflectarray

phase shifters have led to a revolutionary phased array antenna concept – the ferroelectric reflector array (FRA). A phased array is a highly reliable, motionless antenna that can scan its beam with great precision on a microsecond time scale. If an affordable phased array can be produced, it will replace gimbaled parabolic dish antennas in almost all applications. The FRA promises a two to three order of magnitude reduction in manufacturing costs vis-a-vis a state-of-the-art GaAs microwave integrated circuit phased arrays.

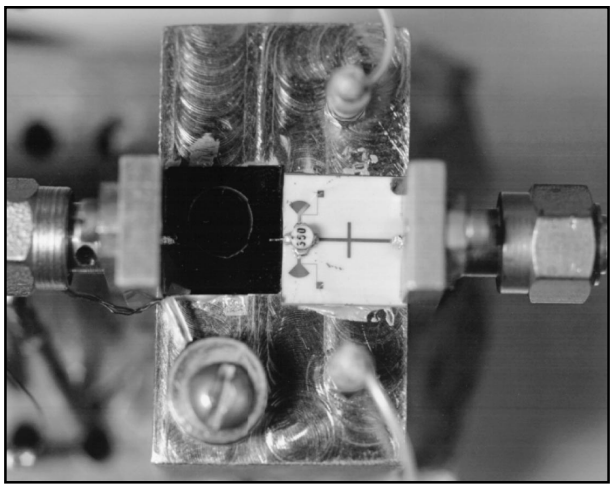
The coupled microstrip phase shifter works by concentrating the RF electric field in a thin (300 nm to 2 mm) ferroelectric layer between two narrow electrodes. From bottom to top, the multilayer structure consists of a conducting ground plane, a single crystal substrate (MgO, $LaAlO_3$, etc.) approximately 0.5 mm thick, a thin ferroelectric film ($Ba_xSr_{1-x}TiO_3$) grown by pulsed laser ablation, and a novel conducting electrode pattern. The electrodes are optimized to pass the microwave signal with minimal attenuation. Bias voltages of up to ~350 V are required. But since the films are dielectric there is virtually no current draw and hence no power dissipation. A quasi-transverse electromagnetic model was developed to explain the operation and the model was shown to be accurate by experiment and full-wave electromagnetic simulation.

This work has led to numerous subsequent publications. We have devised new phase shifters, based on exactly the same principles, but using films that have a Curie temperature above 290 K. An FRA based on these new devices is under development and promises more than a factor of 100 reduction in cost (i.e. <$10 thousand compared to >$ 1 million) for an element array. The cost advantage ensues because the phase shifters and radiating elements can be patterned on the same substrate using standard photolithography. NASA Lewis has a patent pending on the FRA.

As a result of our success in this area, we have been contacted by numerous external organizations in the



Scanning reflectarray antenna



Ku-band cryogenic, PHEMT, ferroelectric tunable oscillator.

commercial satellite communications industry seeking our expertise for their own applications. The FRA was the only technology selected from Lewis by General Motors' Innovation Zone. The Innovation Zone is an institution that exhibits technologies expected to be state-of-the-art in a five to ten year time frame. All indications are that ferroelectrics is an up and coming technology breakthrough that promises tremendous impact for frequency and phase agile microwave circuit applications.

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and refer to Article 1298-4

A Silicon-Germanium Fast Packet Switch for Communication Satellites

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Communication Technology Division

Emerging multimedia applications and next-generation satellite systems will require high-speed switching networks to accommodate high data rate traffic among thousands of users. This scenario required advanced onboard crossbar switching in the gigabit-per second range for communications among satellites. NASA Lewis Research Center (LeRC) has been working closely with industry to develop a state-of-the-art fast packet switch (FPS) in Silicon Germanium (SiGe) for future satellite onboard processing (OBP) needs.

The Satellite Industry Task Force identified the need for onboard processing and switching components with a 100x capacity increase as one of the "grand challenges" for the satellite industry in the 21st century. In response to this challenge, and to achieve full interoperability with terrestrial systems, future generations of onboard processing satellites will require low power and low mass components to enable transmission of services in the 100 Gbps range.

NASA LeRC has funded a contract with Sierra Monolithics, a Minority-Owned Small Disadvantaged Business, to develop a state-of-the-art 10 Gbps per port switch. This promising SiGe CMOS technology enables the design of high-speed circuits at very low power consumption.

Some of the benefits of this promising technology to meet the needs of NASA and the satellite industry include:

- Full interoperability between satellite and terrestrial systems
- Bandwidth efficient systems resulting in 100x improvement in capacity over existing satellite architectures
- The development of high throughput, low power OBP components to support the National and Global Information Infrastructure (NII/GII)

The SiGe FPS is based on a 16x16 SiGe crossbar switch able to transmit and receive data at 10 Gbps per port at very low power and weight requirements. The switch has a robust contention control algorithm and processor that is suitable for OBP applications. The table shows a comparison between the state-of-the-art vs. SiGe FPS

Parameter	*state-of-the-art*	*FPS technology*	*Improvement*
Data Rate	***1.2-2.5 Gbps/port***	***10 Gbps/port***	***4-8x improvement***
Aggregate Throughput	***~ 20 Gbps***	***160 Gbps***	***8x improvement***
Power Consumption	***~10 W***	***<5 W***	***50% improvement***

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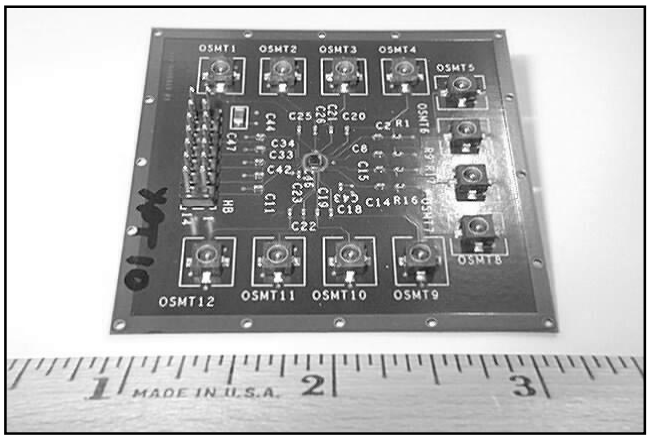
(Fast Packet Switch continued.)



4×4 Protype board successfully tested in 1998.

technology. The figure shows a picture of a 4×4 prototype board already developed and tested by Sierra Monolithics earlier this year. Right now, Sierra Monolithics has designed and started testing of the 16×16 FPS.

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and refer to Article 1298-5

A More Accurate and Efficient Technique to Obtain Helical Traveling-Wave Tube Interaction Impedance Using Computational Methods

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Electron Device Technology Branch

The phenomenal growth of satellite communications has created great demand for traveling-wave tube (TWT) amplifiers. Many of NASA's deep space missions will also rely on TWT's to return scientific data over great distances. Although helix slow-wave circuits remain the mainstay of the TWT industry because of their exceptionally wide bandwidth, until recently it has been impossible to accurately analyze helical TWT's using their exact dimensions because of geometrical complexity. For the first time, an accurate three-dimensional helical model was developed at Lewis that allows accurate prediction of TWT cold-test characteristics including operating frequency, interaction impedance and attenuation. In addition, it was found that the computational model allows TWT designers to obtain more accurate values of interaction impedance than are possible using experimental methods.

Obtaining helical slow-wave circuit interaction impedance is an important part of designing TWT's as this parameter is related to TWT gain and efficiency. This parameter cannot be measured directly; thus, conventional methods involve perturbing a helical circuit with a cylindrical dielectric rod placed on the central axis of the circuit and obtaining the difference in resonant frequency between perturbed and unperturbed circuits. A mathematical relationship has been derived between this frequency difference and interaction impedance [1]. However, because of the complex configuration of helical circuits, deriving this relationship involves several approximations. In addition, this experimental procedure is time-consuming and expensive, but until recently it was thought to be the most accurate means of determining interaction impedance.

The advent of an accurate three-dimensional helical circuit model [2] has made it possible to fully investigate standard approximations made in deriving the relationship between measured perturbation data and interaction impedance. The most prominent approximations made in the derivation were addressed and fully investigated for their accuracy using the three-dimensional electromagnetic simulation code MAFIA (Solution of MAxwell's equations by the Finite-Integration-Algorithm) [3, 4]. It was found that several approximations introduced significant error [5].

To further prove the validity of the three-dimensional helical model using MAFIA, the experimental perturbation method was duplicated by simulating the helical circuit with a cylindrical dielectric rod of size and material properties consistent with the experimental setup. The difference in frequency between perturbed and unperturbed circuits was obtained. Then, interaction impedance was calculated using the approximate formulation relating frequency difference to interaction impedance. The results compared with measured values in Figure 1 emphasize the accuracy of the code. The on-axis interaction impedance was then calculated using the exact formula using MAFIA and is also plotted in Figure 1. The results calculated directly with MAFIA are consistently lower than measured results with an average difference of 26.6%.

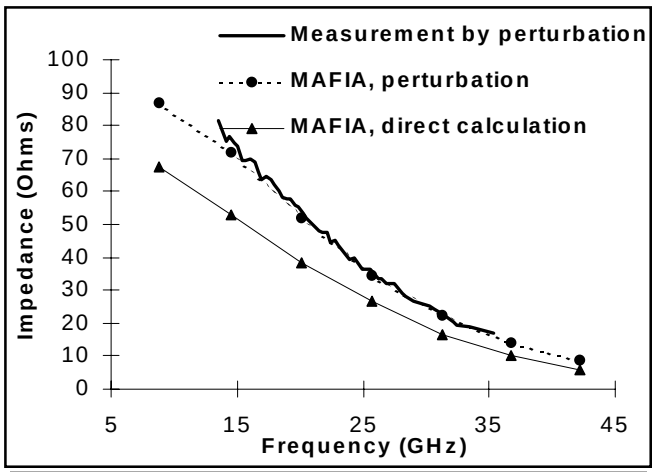

Figure 1.— On-axis interaction impedance obtained by measurement and using MAFIA with the perturbation method and direct calculation.

The demonstrated inaccuracy of the approximations in the derived experimental impedance formula along with the large discrepancy between measured impedance data and direct calculations using MAFIA verifies that a more accurate value of interaction impedance can be obtained using three-dimensional computational methods. Compared to performing costly and time-consuming experimental cold-test measurements, this implies a large savings in time and cost associated with fabricating and testing circuits or scaled circuit models, as well as more accurate results. This is particularly meaningful at higher frequencies where experimental cold testing is more time-consuming, less accurate because of necessarily tight tolerances and more difficult to perform.

For more information please e-mail us at:

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and refer to Article 1298-6

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Preservation Of Cassini Radio Science Experiments on Saturn and Titan

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Communications Technology Division

The Cassini mission to Saturn is an international venture with participation from NASA, the European Space Agency, and the Italian Space Agency. The spacecraft is the best-instrumented probe ever sent to another planet and will produce the most complete information about a planet system ever obtained. Launched from Cape Canaveral in October 1997, it is scheduled to arrive at Saturn in July 2004. After arrival, Cassini will orbit Saturn about 60 times over a period of four years. During this time, the Radio Science Subsystem will be used to investigate the atmosphere and rings of Saturn and the atmosphere of its largest moon, Titan.

A critical component in the Radio Science Subsystem (RSS) is a traveling-wave tube (TWT) that was designed at Lewis and built by Hughes Electron Dynamics Division. The function of the TWT will be to amplify downlink microwave signals at a frequency of 32 GHz for a number of experiments. These include occultation experiments in which the microwave signal will be beamed through rings and atmospheres toward Earth. The received signals will be analyzed to study the radial structure and particle size distribution within Saturn's rings and to determine the temperature and composition profiles of the atmospheres of Saturn and Titan. The nitrogen-rich atmosphere of Titan is of special interest because it is the only dense atmosphere of a moon in our solar system and is thought to resemble that of the primordial Earth. The RSS will also be used to more accurately determine the mass and size of Saturn and its moons, to investigate the solar corona, and to search for gravitational waves from outside the solar system.

(continued on page 10)

(Cassini Radio Science continued.)

These RSS experiments were almost cancelled after tests of the TWT in 1995 showed an unexpected ghost signal at a frequency of 35 GHz. Curiously, this signal only occurred at power levels below that at which the TWT was to be operated. However mission planners were very concerned that a small change in operating conditions might cause the spurious signal to occur at higher power levels and interfere with detection of the desired signal at 32 GHz. Because the cause of the ghost signal could not be determined experimentally, an in-house effort was initiated at Lewis to try to determine the cause of the signal using the Lewis-developed computer analysis techniques.

The extensive computer analysis determined that the ghost signal is an intermodulation product of the 32-GHz signal with a 67-GHz oscillation. The oscillation is induced by coupling to second harmonic beam current, which is significantly high only at low power levels. The analysis indicated that possible changes in operating conditions would not cause the ghost mode to be a problem. The analysis convinced JPL to not remove the RSS from the Cassini spacecraft and the experiments will proceed as originally planned.

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Space Communications *News Briefs*

Jennifer J. Sibits
ADF Corporation, Public Relations

Critical Design Review for K-band Transmit Array Complete

Raytheon Systems Company recently completed the Critical Design Review for a high capability K-band transmit array antenna. The antenna is a 19 gigahertz, electronically steerable phased array with capability to transmit data from low Earth orbit to a small Earth terminal at rates up to 1.2 gigabits per second. The array is capable of transmitting two independently steered beams at 622 megabits per second per beam. Once completed, the array will be used in a high data rate Direct Data Distribution (D3) flight experiment during a future Space Shuttle mission.

Raytheon Systems Company is developing the array under a cooperative agreement with NASA Lewis Research Centers Space Communications Program.

For related Raytheon News Release on this topic contact:

Raytheon Systems Company,
Cynthia Curiel at (520)794–7810

Postage Stamp Size Antenna Technology

Research done at NASA Lewis Research Center on a small, postage stamp sized antenna is more than just "cool stuff." Such is the vision of Federal Data Corporation (FDC) who just issued an official notice of allowance by the U.S. Patent office on October 21, 1998. Consisting of an electrical conducting transparent material, the small antenna can be coated on any clear surface such as plastic, glass, computer displays or TVs. (see prior article by R. Kunath, pg. 4)

While the antenna has yet to find its place on a NASA mission, it certainly has great potential for use in terrestrial and wireless communications in the 20-100 GHz frequency range. NASA looks forward to Federal Data's manufacturing efforts and awaits the opportunity to claim the transfer of this break-through technology as a true *NASA Technology Transfer* success story.

For related FDC News Release on this topic contact:

Federal Data Corporation,
Robert Fowler at (216) 977–1389

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and refer to Article 1298-8

Space Act Agreement Signed

A Space Act Agreement was signed between NASA Lewis Research Center and Manufacturing Instrumentation Consultant Company of Cleveland, Ohio. NASA will work with this small business to develop near field electromagnetic probes. These probes can be used to detect imperfections in metal structures and non-uniformity in insulators. NASA Lewis is invesitigating the use of these probes for improving the yield of TWTA's.

ACTS Presents at 20th Annual Satellite Communications Expo & Conference (SCEC '98)

Jennifer Sibits
ADF Corporation
Space Communications Program Outreach

The 1998 SCEC conference served to bring the capabilities of high end technologies closer to world satellite service users. The conference program featured high powered panel discussions and technical sessions and included participation by two of our own industry partners. The show exhibit hall featured industry and government specialists showcasing latest technologies for hardware, system integration, network management and software.

Panel sessions entitled: Tackling the Rain Fade Problem for Ka-band Systems, and Wholesale Internet Access by Satellite included participation by Mr. Frank Gargione ACTS Project Manager at Lockheed Martin, and Mr. David Beering of Infinite Global Infrastructures. Mr. Gargione and Mr. Beering, have a great deal of hands-on experience with the satellite itself and the many many experiments accomplished on the ACTS project.

On the exhibit floor, the Space Communications Program event team debuted a newly created interactive multi-media tool entitled: 118x – Dispelling the Myth. The tool illustrated the technical and programmatic challenges overcome by the 118x experiment team when achieving TCP/IP connectivity over the ACT satellite.

Space Communications Program display featuring ACTS at SCEC '98.

Opposite the multi-media demonstration was a display that focused on the goals for the extended operations of ACTS project. Members of the Space Communications Program event team talked with conference attendees about the continued operations of the ACTS and its experiment opportunities.

SCEC '98 was held at the Washington Convention Center in Washington, DC this past September.

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Space Communications Program Outreach

NASA Lewis
OPEN HOUSE '98

Janice Zarrelli,
ADF Corporation
Space Communications Program Outreach

The Space Communications Program participated in the 1998 NASA Lewis Open House held this October 10th and 11th. This event enabled an opportunity to inform and educate our local public about the work we do in advanced satellite and space based communications. Many Open House attendees listened closely to explanations about how our research is used in space and how it influences better ways to communicate right here on earth! Thus once again, sending the message that NASA Lewis Research Center's Space Communications Program is

"Changing the Way NASA and the Nation Communicate through Space."

(continued on page 12)

Our SCP exhibit was located in the hangar and displayed a bright and brilliant graphic that highlighted the Advanced Communications for Air Traffic Management (AC/ATM) project. A software simulation was demonstrated that gave folks a chance to view the AC/ATM concept of "free flight", where pilots chose their flight path. SCP personnel were on hand to answer the curious questions posed by demo viewers. While this portion of our display intrigued the minds of some of our adult visitors, younger on-lookers played a multi-media game that presented facts about Global Positioning Systems (GPS).

The 1998 Lewis Open House gave us an opportunity to present, to the local public, the kind of technology and research programs we work on, right here at NASA in Cleveland, Ohio that has a direct impact on their everyday lives. Nearly 50,000 people were in attendance.

Congratulations on a job well done! Bravo!

For more information please e-mail us at:

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and refer to Article 1298-10

John Mudry sparks interest in future generations at Open House '98.

Multi-platform, High Speed Communications using ACTS Experiment 118X

Michael Zernic
Project Development and Integration Branch
Space Communications Office

NASA Lewis Research Center has catalyzed and led a cross-industry partnership among competitors in the satellite, telecommunications, and computing industries. Eighteen (18) industry and government organizations have jointly dispelled the myth that conventional internet protocol (TCP/IP) and high speed applications do not perform well in hybrid (satellite-terrestrial) network architectures, especially those involving geo-stationary satellites. A series of investigations using the Advanced Communications Technology Satellite (ACTS) between San Francisco, CA and Cleveland, OH were concluded by the team on September 30, 1998. The findings were discussed in a team meeting at Lewis on November 10, 1998 and follow-on activities are currently being considered.

Record throughput performances were achieved in both a homogeneous (over 500 megabits/second) and a heterogeneous (over 350 megabits/second) vendor environment. With the vision of interoperable communications, extending internet protocol into the space environment and making all spacecraft nodes on the internet are key long-term goals. Therefore, this work is especially important to international standards bodies, NASA's Enterprise mission data services, NASA's migration to commercial assets, and Johnson Space Center's Consolidated Space Operations Contract objectives.

The 18 partners contributed over $1.2M worth of equipment and engineering over a 6 month period and are listed below:

- Computing Industry—Sun Microsystems, Microsoft, Intel, Digital Equipment Corp., Pittsburgh Supercomputing Center, Netmanage/FTP Software
- Telecommunications Industry—Sprint, FORE Systems, CISCO Systems, Ampex Data Systems

- Satellite Industry—Hughes Space & Communications, Space Systems/LORAL, Spectrum Astro, Lockheed Martin

- Government—NASA Lewis (Space Communications Office and Communications Technology Development made significant contributions!), NASA Johnson Space Center, Jet Propulsion Laboratory, Naval Research Laboratory, Lawrence Livermore National Laboratory

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and refer to Article 1298-11

Hawaii's Jim Crisafulli is Honored at PACMEDTEK

Michael J. Zernic
Project Development and Integration Branch
Space Communications Office

Jim Crisafulli, Science and Technology Officer of the State of Hawaii's Department of Business, Economic Development & Tourism, was honored at the PACMEDTEK Conference in Honolulu on August 19, 1998 for his long time involvement with the ACTS Program. The last 10 years has been testimony to his sincere commitment of the promotion of technology and its meaning to the development of the State of Hawaii as well as to the Nation. Pete Vrotsos, Manager of NASA Lewis Research Center's Space Communications Office, presented the honor on behalf of the NASA ACTS Program in which the inscription reads "Excellence in ACTS Experiment Advocacy". Distinguished persons present included Mr. Ben Cayetano, Governor of Hawaii, and General Adams, Director of the Army Tripler Medical Center.

One of the main PACMEDTEK's themes showcase advances in Pacific, Hawaii, and US Healthcare Information Technologies. The advancement of information technologies, in general, has been made possible through the efforts exerted by the State of Hawaii. Specifically, the collaborative efforts with NASA utilizing the Advanced Communications Technology Satellite have promoted this technology advancement

During the 1980's and early 1990's, Senator Inouye and past Governor Waihee proved to be instrumental in both programmatic support and technology implementation. The original spacecraft design provided coverage only in the contiguous 48 states of the US, thereby limiting access to ACTS' key technologies of:

- High powered, electronically hopping spot beam coverage
- Processing and switching onboard the spacecraft and pioneering of the next communications frequency band, the Ka-band

Hawaii's sincere pursuit of leading the advancement of information technologies included deep support for NASA and participation in the ACTS Program. This leadership yielded the implementation of a mechanically steerable antenna—only 3 feet in diameter, and over 33,000 kilometers above—which could be pointed at Hawaii and thereby enabling ACTS' technologies to reach nearly the entire Western hemisphere.

In the formulation of the ACTS experiments program, it was never envisioned that ACTS would be supporting:

- A robotic exploration of an Alaskan volcano
- U.S. Army troops in Haiti during Operation Democracy
- Distance education in South America

Pete Vrotsos honors Jim Crisafulli for his advocacy of the ACTS experiments program.

(continued on page 14)

(Crisafulli Honored continued.)

- PBS and Passport to Knowledge in the educational and science series
  - —Live from the Stratosphere
  - —Live from the Antarctic
  - —Live from the Rain Forest
- Oil exploration in the Gulf of Mexico
- Or providing advanced satcom to the crew of the USS Princeton in the Pacific Ocean
- Sophisticated remote science applications
- Hybrid interoperability
- Healthcare/telemedicine

The Advanced Communications Technology Satellite Program is one of NASA's premier technical accomplishments and contributions to the Nation. It has trailblazed the path for the next generation commercial satellite systems, infrastructure technologies, and high performance applications.

Without vision…without dedication….without excellence, we'd just be talking about technology, *not doing it!*

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and refer to Article 1298-12

Space Communications Program Vision Statement

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"Changing the way NASA and the Nation Communicate through Space"

Lewis Showcases Space Comm Technology at Inspection '98

Nancy Horton
Project Development and Integration Branch
Space Communications Office

Inspection '98, held at the Johnson Space Center from Oct 14-16 offered industry executives, educators and community leaders a "behind-the-scenes" look into NASA's activities in human spaceflight, the Space Shuttle program, the International Space Station and the extraterrestrial material and life sciences program. This annual event is one of NASA's many ways of sharing technologies, expertise and state-of-the-art facilities with the business and academic community. The Lewis Space Communications Program was invited to participate with colleagues from the Jet Propulsion Lab (JPL) and the Goddard Space Flight Center (GSFC) in the Space Operations and Management Office (*SOMO) exhibit. The Lewis demonstration entitled "Applying Space Communications on Earth" employed an interactive multi-media tool which allowed visitors to explore technology and application focus areas most relevant to their specific interests while learning some general facts about our program.

*(See cover story from Summer '98 edition to learn more about SOMO's role in Space Communications)

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and refer to Article 1298-13

Global Positioning System (GPS)—A Joint Effort Between Government and Industry

James E. Hollansworth
Spectrum Management Branch
Space Communications Office

NASA, NOAA, FAA, USCG, US GPS Industry Council, and the Air Transport Association have jointed together to protect spectrum used by the Global Positioning System (GPS) from encroachment by future mobile satellite services. This group prepared an information booth on GPS that appeared at the International Telecommunication Union Plenipotentiary '98 Technology Demonstration at Minneapolis, Minnesota, explaining the uses and benefits of GPS to the World.

The primary intent of the information booth was to explain the benefits GPS provides across a host of applications including: Agriculture, Aviation, Environmental, Marine, Public Safety, Rail, Recreation, Space, Surface, Surveying and Timing. Visitors to the booth had an opportunity to hear narratives pertaining to the above applications in three languages (English, French or Spanish). An interactive multimedia presentation depicting the above applications was also available and provided a basic introduction to the GPS system along with highlighted applications from countries around the world.

Protection of the radio frequency spectrum allocations utilized by the GPS, and a similar Russian system called GLONASS, is critical to meeting the ever growing demand for the navigational aids made possible by these systems. GPS and GLONASS make up the Global Navigational Satellite System, or GNSS, a system that can be used to locate anything or anyone at any location on or near the surface of the earth. NASA is seeking to secure the necessary frequency allocations to allow GPS signals to be used in space on a protected basis. Nearly all future space missions, including the Space Shuttle and International Space Station, will use the GPS for precise navigation.

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Pictured:
Front Row (L to R) Mike Leary (Trimble Navigation), Donald Willis (FAA), Barbara Wamsley (ADF Corporation). Back Row (L to R) Joseph Gispert (US Coast Guard), Carlos Hadba, Trimble Brazil, Tomas Rehn (Swedish GPS Council), Jack Haneklau (Air Transport Association), Mike Swiek (US GPS Council), Greg Thompson (Air Transport Association) and James Hollansworth (NASA LeRC).

"The Essence of Leadership and Technological Advancements"

Janice Zarrelli
ADF Corporation
Space Communications Program Outreach

Three prominent individuals from the Space Communications Program, Nancy Horton, Roberto Acosta, and Michael Zernic were acknowledged and rewarded for their proven excellence in leadership and technology advancements.

Project Manager, Nancy Horton, received the "EXCEPTIONAL SERVICE MEDAL", on August 19th by NASA Lewis Director, Donald Campbell and Lieutenant General Spence Armstrong, Associate Administrator for Aeronautics and Space Communications Program, for her numerous contributions to the NASA and the Space Communications Program. The award commemorates her for "outstanding leadership" and places her among a select group of NASA employees receiving this high honor.

Roberto Acosta, Senior Engineer, was nominated for the "HISPANIC ENGINEER NATIONAL ACHIEVEMENT AWARD", HENAA, on May 11, 1998. The mission of HENAA is to nationally seek out an individual who's proven dexterity and wisdom deserves acknowledgement, recognize their contributions and achievements, and endorse Hispanic excellence in the field of science and technology. At this year's 10th Anniversary Conference in Houston, Texas on October 8-10, Roberto Acosta was honorably mentioned for his progressive accomplishments in the development of the multiple beam antenna system for the Advanced Communications Technology Satellite, ACTS.

On August 21, 1998, Michael J. Zernic was honored at his alma mater with the University of Dayton School of Engineering "ALUMNI AWARD of EXCELLENCE". This award recognizes alumni who have made significant contributions to their profession, especially in engineering or scientific areas that benefit society, exercise technical innovation, and yield economic impact. Zernic's contribution and accomplishments in NASA Lewis ACTS Experiments Program were highlighted as well as his previous technology and mission operations work in NASA's Space Station Program.

Congratulations to you all!

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and refer to Article 1298-15

ACTS . . . Transitioning to a New Image, a New Identity

Robert A. Bauer
Project Manager
Advanced Communications Technology Satellite

Introducing A New ACTS Logo!

This new logo commemorates the transition of the ACTS project to the new inclined orbit phase of operations and its role as a key contributor in achieving our Space Communications Program vision of
"Changing the Way NASA and the Nation Communicate through Space".

The new logo boldly illustrates the strength of the program with the heavy solid block lettering of the acronym ACTS placed across an image of the globe.

The globe symbolizes the role the satellite continues to play in bringing swift realization of global communications using both space and ground based systems.

The challenge of operating the satellite in an inclined orbit is represented by the slanted orbital ring.

The diamond symbolizes the satellite itself and the stellar performance the ACTS program has achieved over the past five years.

The four points of the diamond represent the four technology research goals as described in the 1998 ACTS Experimenters Opportunity Guide.

- ***Demonstrating NASA and other government use of future satellite services***
- ***ATM,IP, and other protocols over satellites, including interoperability with terrestrial networks***
- ***Evaluating satellite inclined orbit operations***
- ***New Ka-band technology and hardware verification***

The new identity for the ACTS project is just one of many on-going steps being taken to develop and promote a fresh new image for NASA Lewis Research Center's Space Communication Program.

We believe that a change in outward appearance will cause people to ask questions and open new avenues of dialogue that will help position the project for achieving its technology goals.

Development and implementation of this and other identity programs are accomplished by the SCP Outreach Team. Members of the Outreach Team will be happy to answer any questions. So please send your questions by email to *Spacecom@lerc.nasa.gov*

For more information about the ACTS Project, please e-mail us at: ***Spacecom@lerc.nasa.gov***
and refer to Article 1298-16

When the Gales of November Come Early – Another ACTS First!

Michael Zernic
ACTS Experiments Manager

Since the beginning of NASA Lewis Research Center's Advanced Communications Technology Satellite (ACTS) experiments program, mobile communications have been one of the most promising areas for ACTS technology contribution. In particular, the U.S. Navy has been extremely interested in using ACTS for the promotion of satcom technologies and the advancement of communication capabilities in a "stressed, ship-at-sea" environment. Until October 1998, NASA Lewis Research Center ACTS project had utilized JPL's Broadband Aeronautical Terminal for such shipboard investigations on an Aegis class guided missile cruiser, the USS Princeton, as well as a commercial seismic data acquisition vessel used in the petroleum industry, Schlumberger's Geco Diamond. Although impressive from both a satcom and a networking perspective by establishing a record benchmark, those technical objectives were limited to a bi-directional capability of 2 Megabits per second.

In October 1998, NASA Lewis Research Center and the Naval Research Laboratory embarked on a collaborative effort designed to investigate the technical feasibility of a bi-directional mobile network operating at 45 Megabits per second – 22 times faster than the previous record! This network involved a moving vessel at sea, a fixed ground station, and access into the terrestrial networks (e.g., internet). NASA Lewis Research Center's participation was relevant to the Center's collaboration and technology transfer efforts as well as being extremely relevant to the HEDS Enterprise technology thrusts for mission services, high performance communications, and interoperability. The Naval Research Center's participation was relevant to the Office of Naval Research Communications Technology Program efforts to enhance satcom connectivity to naval forces including investigating those technologies and system attributes pioneered by ACTS which will be commercially available in the future. Specific technical goals included conventional and advanced tracking comparisons, operate tracking schemes in a stressed environment (vessel at sea, inclined orbit satellite), extrapolation of tracking scenarios for use in future LEO/MEO satcom systems, and the investigation of high speed data transfer applications. These applications included TCP/IP based file transfers, interactive and variable TCP/IP based multimedia, production quality video, and CD quality audio occurring simultaneously in a roll-pitch-yaw environment – especially challenging in waters outside the breakwall in Lake Michigan this time of year. The achievements of this NASA-NRL collaboration were so successful that system modifications and new technical goals are already being considered for additional testing with ACTS!

The small craft used was the 45' Bayliner Motor Yacht *Entropy* (pictured below) based in Chicago, IL and operated on Lake Michigan. The shipboard terminal consisted of a 1.0 meter antenna (under the radome indicated by the black arrow) with a tracking pedestal provided by SeaTel, Inc. The antenna system was integrated for Ka-band operation at SeaTel by a team of engineers and technicians from SeaTel, NASA, and NRL, and incorporated hardware contributions by all three organizations. Other participants included Hill Mechanical Group, FORE Systems, Xicom Technologies, Ratheon Marine Company, and COMSAT Labs. The shipboard station communicated via the ACTS satellite with the NASA Lewis ACTS HDR ground station in Cleveland, Ohio and then into the established terrestrial network.

The small 45-foot Entropy *housed the test and application equipment as well as the tracking antenna under the radome indicated by the arrow.*

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The Direct Data Distribution (D^3) Project

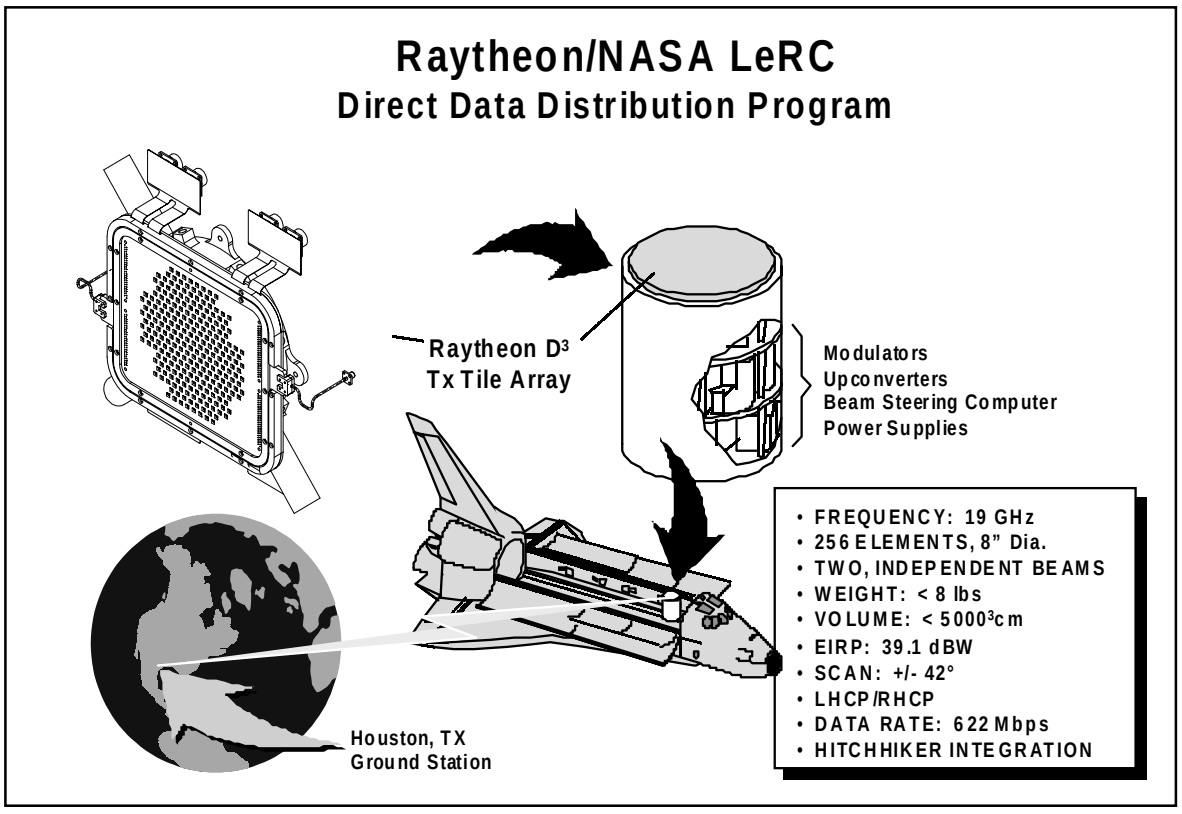
Lawrence W. Wald
Project Manager of D^3

The Direct Data Distribution (D^3) Project will demonstrate an advanced, high-performance communications system that transmits science data directly from Low-Earth Orbiting (LEO) spacecraft to small receiving terminals on the Earth. The STS-based communications package will utilize a solid-state, K-band phased array antenna that electronically steers the radiated energy beam toward a low-cost, tracking ground terminal, thereby providing agile, vibration-free, electronic steering at reduced size and weight with increased reliability. Additionally, the array-based link will demonstrate new digital processing technology that will allow transmission of substantially increased amounts of data collected from the International Space Station (ISS) or other LEO spacecraft directly to NASA field centers, principal investigators, or into the commercial terrestrial communications network.

The flight hardware for D^3 will be produced from advanced technology components developed under research and development programs in the Communications Technology Division (CTD) of the Lewis Research Center (LeRC). These components include: a Monolithic Microwave Integrated Circuit (MMIC)-based, 19.05-Gigahertz (GHz), electronically-steerable or phased array antenna; a bandwidth and power efficient digital encoder/modulator; and a low-cost, autonomous, tracking ground terminal. Many of these technologies are already of a sufficient maturity that airborne flight demonstrations have been successfully conducted. The Goddard Space Flight Center Shuttle Small Payloads Program will provide a timely and cost-effective flight opportunity via their Hitchhiker carrier to demonstrate the technology for the first time in space.

D^3 will be conducted primarily as an in-house project at LeRC, involving civil servant staff and supporting contractor personnel. The Communications Technology Division will provide the Principal Investigator(s) responsible for the primary technology components of the experiment. The D^3 project is managed out of the Space Communications Office (SCO) of the Lewis Research

(continued on page 20)



(D^3 Project continued.)

Center. Supporting/contractor personnel will be responsible for most of the engineering design, fabrication, assembly, and testing of the payload and ground systems.

The flight payload will be packaged within a single standard, 5-ft^3, Get-Away-Special (GAS) canister mounted in the Space Transportation System (STS) orbiter cargo bay, and supported by the Hitchhiker carrier avionics and power systems. Data from the experimental payload will be transmitted directly to a small, autonomous ground terminal that will feature a 1.8-meter [diameter] reflector-based antenna mounted to a precision tracking mechanism. The ground terminal will also be constructed using technology products derived from the CTD research program.

This communications link is essential to the success of future NASA missions, especially those in polar orbits, as it provides the means to manage the unprecedented amounts of data to be generated by space-based instruments. Additionally, the components used in the D^3 system are being designed in concert with commercial developers who will use similar technology in future commercial space communications systems. This approach will facilitate the ultimate transition of NASA to those communications services, resulting in substantial reductions in operations costs. The project will demonstrate transmission of data, in bursts, at throughput rates up to 1.2 gigabits per second (GB/s) with fiber-like quality of service, thereby far exceeding the data transfer capability presently available to NASA. The design readily lends itself to a series of experimental and operational modules, scaleable in capacity to both lower and higher data throughput rates.

A support service contractor team has been put in place to perform several feasibility studies and work with CTD personnel to develop requirements for the K-band phased array. The Principal Investigator(s) from CTD will be chosen in the 1Q of FY99. A proposed flight date for the experiment is in the 1Q of FY00.

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Advanced Communications Technology for Aeronautics

Konstantinos (Gus) Martzaklis
Project Manager
Advanced Communications for Aeronautics

In support of the NASA Advanced Air Transportation Technologies Project (AATT) and the NASA Aviation Safety Program (AvSP), the NASA Lewis Research Center is developing advanced communications technologies to: (1) improve the capacity and throughput of the National Air Space system; and (2) to enable the accurate and timely dissemination of aviation weather information to aviation users. Two current projects, the Advanced Communications for Air Traffic Management Project as part of AATT and the Advanced Communications for Aviation Weather Information Project as part of AvSP, are spearheading the research and technology development.

Advanced Communications for Air Traffic Management Project AC/ATM):

The AC/ATM Project is a Level IV sub-element task of the Advanced Air Transportation Technologies (AATT) Element of the NASA Aviation System Capacity Program (ASC). AATT is developing new technologies and tools that will enable Free-Flight; an operating system in which pilots will have the freedom to select their path and speed in real-time. The AC/ATM Project, as part of AATT, specifically addresses the Aeronautics & Space Transportation Technology (ASTT) Enterprise Pillar One (Global Civil Aviation) Enabling Technology Goal of:

"While maintaining safety, triple the aviation system throughput, in all weather conditions, within 10 years."

The current system will not provide the necessary increase in system capacity that is required without a state-of-the-art communications infrastructure that supports new applications, higher data rates, global connectivity, seamless integration, and rapid reconfigurability.

The goal of the AC/ATM Project is to enable a communications infrastructure that provides the capacity, efficiency, and flexibility necessary to realize the benefits of the future mature Free-Flight environment. The capabilities and scope of communications technologies needed to accomplish this goal depend on the characteristics of

the future Free-Flight environment. There are many different operational concepts currently being proposed for a future ATM system to enable user flexibility and efficiency. Whichever approach is implemented, transparent real-time communications will be a necessity.

Although the AATT program is primarily targeting jet transport-class aircraft with revenue producing operations, other aircraft segments (general aviation, cargo, business jet, regional, commuter etc...) are additionally considered since these segments also contribute to system capacity.

The AC/ATM Project is organized along four concurrent sub-elements consisting of requirements and architectures definition, hardware experiments and demonstrations, advanced technology development and a communications integrated product team which acts as a technical steering committee for the project.

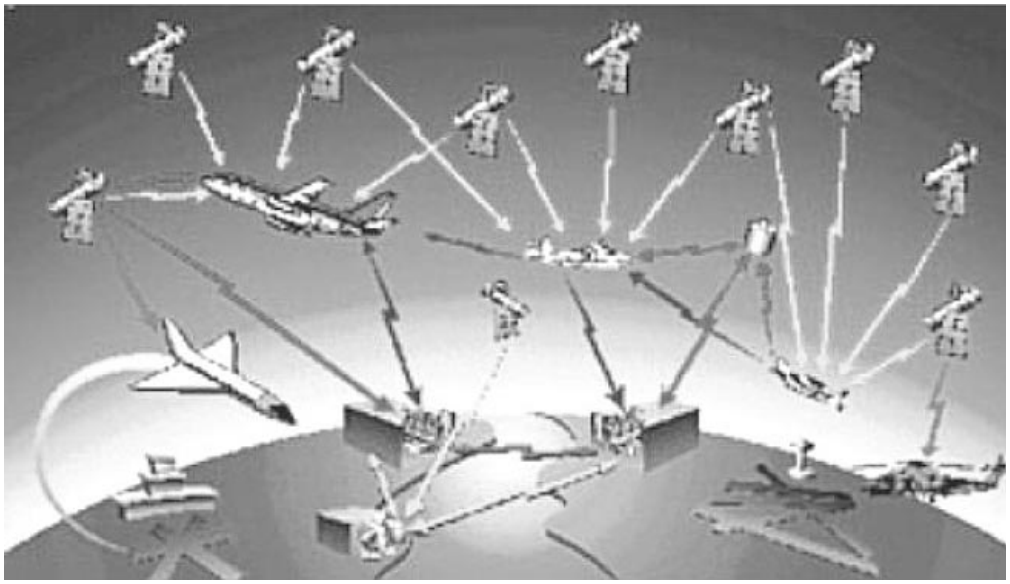
The technical thrust of the AC/ATM Project is targeted at the design, development, integration, test and demonstration of enabling satellite communications systems and technologies for global, broadband aeronautical communications. To this end, the project products are addressing requirements for the near, mid and far term timeframes. Generally, the near-term portion involves demonstrating derivative and new applications and concepts for ATM utilizing the emerging “little” and “big” LEO satcom systems such as Iridium, Globalstar and Orbcomm. The mid-term portion is targeting asymmetrical services (high-rate reception, low-rate transmission) and the long-term portion addresses 2-way broadband services. The project is executed via a combination of in-house and contracted efforts in partnership with other government organizations and industry.

Advanced Communications for Aviation Weather Information (AC/AWIN) Project:

The AC/AWIN Project will become a Level IV project of the Weather Accident Prevention Element of the Aviation Safety Program (AvSP) in FY 2000. During FY 1999, the AC/AWIN work is supported under the Aviation Operations Systems base program. As part of the AvSP, the AC/AWIN project will address the Aeronautics & Space Transportation Technology (ASTT) Enterprise Pillar One (Global Civil Aviation) Enabling Technology Goal of:

“Reduce the aircraft accident rate by a factor of five within 10 years, and by a factor of 10 within 20 years.”

On February 18, 1997 NASA held the first in a series of four workshops to initiate the Aeronautics Safety Investment Strategy Team (ASIST) activity which defined the technical objectives of the AvSP. The team was composed of 35 members representing the meteorological community (FAA, DoD, National Weather Service, NCAR), the Small Aircraft Manufacturers Association, the Air Transport Association, the aircraft manufacturers and airline industries, and universities.



A “Satellite-based communications, navigation, and surveillance architecture for aviation”.

(continued on page 22)

(Advanced communications continued.)

An outcome of the ASIST activity was a recommendation for a significant effort in weather accident prevention. The Weather Accident Prevention element of AvSP addresses these recommendations. Within the recommended weather initiatives, data dissemination was considered to be the most critical element of weather accident prevention. The AC/AWIN Project addresses the data dissemination portion of the program.

The primary goal of the AC/AWIN Project is to identify and develop new technologies and techniques to support the digital weather information communication between airborne and ground based users, and the weather information providers. The communications requirements will be focused at advanced aviation weather information systems intended to improve safety in accordance with national goals.

The approach first requires an inventory assessment of current weather tools being utilized for aviation safety and their specific communications requirements. The next step is to evaluate the near and far term tactical and strategic weather tools currently being developed (as well as those planned for development) within the public and private sectors and their associated communications requirements. With the communications requirements in hand, the next phase will investigate current communications solutions being utilized (satellite, HF, VHF, etc.) and their future appropriateness in supporting the emerging near and far term weather data tools. At this point, recommendations/conclusions will be made on the feasibility of using the existing communications infrastructure in support of the future tools. Any and all communications deficiencies associated with implementing the future weather data tools will be identified and potential mitigating solutions will be presented. Potential solutions could include the use of advanced communications technologies developed for other markets/programs properly modified for aviation weather purposes and/or the actual development of enabling technologies as necessary. Regardless of the solution path, appropriate simulations, technical experiments and concept demonstrations will be performed in order to evaluate and validate the various potential solutions.

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How Are We Doing?

We encourage your feedback as we continue to develop the Space Communications Technology Link newsletter into a comprehensive Outreach Publication.

Information reported in the S.C.T.L. is the result of work performed by members of both the Communications Technology Division and the Space Communications Office. Together these two organizations influence the success of the entire Space Communications Program.

We would like to hear from you!
Please send us an e-mail at:

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or call at: **(216) 433-3291**

and refer to Article 1298-20

Communications Technology

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and refer to Article 1298-Listings

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